Forum of Electromagnetic Research Methods and Application Technologies (FERMAT)

SOFIA UNIVERSITY ST. KLIMENT OHRIDSKI

Influence of Dielectric on Wearable Textile

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Abstract

In this paper, we consider the simultaneous influence of the dielectric anisotropy of textile fabrics on the wearable antennas/resonators and their bending. A set of measurements of flat and bent microstrip rectangular resonators on selected pure isotropic and anisotropic textile substrates have been performed, and the results have been compared with simulations. They show that both parameters (*actual substrate anisotropy and curvature radius*) have concurrent influences on the resonance behavior of such structures and we managed to separate these effects and

Anisotropy and Bending Antenna Properties

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initially to explain them. These influences are rather complex: they depend on the actual dielectric anisotropy of the textile fabrics (typically 4-12% for such types of woven or knitted materials as we have shown in our previous papers and in this research), *from one side*, and to the actual curvature of the investigated planar radiators (bending angle/radius), *from another side*, and on their local combination.

Acknowledgments

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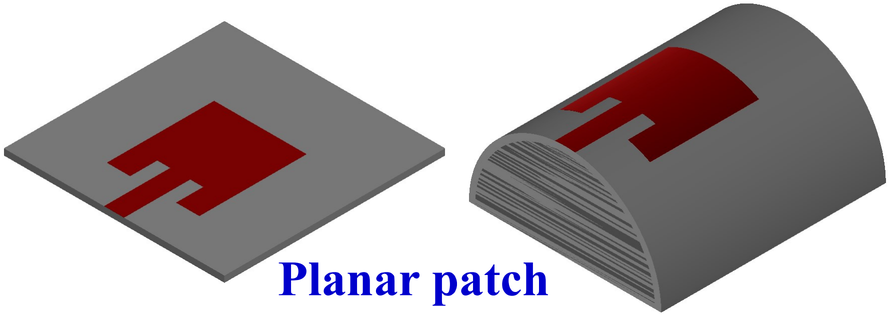
Introduction: We observed different effects of bending and substrate anisotropy in wearable antennas' and resonators' behavior

Wearable patch bending and substrate anisotropy – competitive effects; how to separate them?



Planar patch

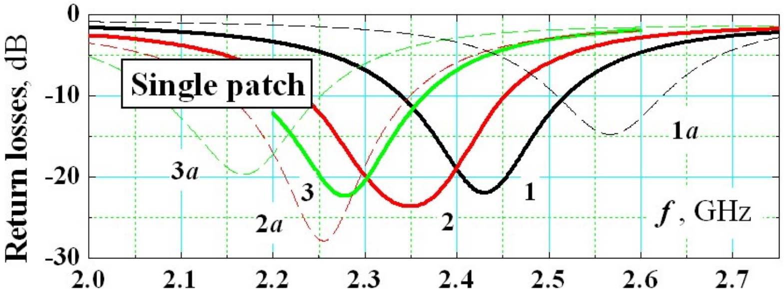
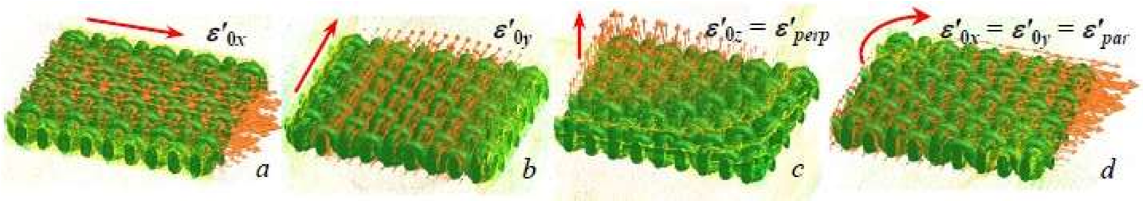


TABLE IV. SIMULATED PATCH ANTENNA PARAMETERS ON ISOTROPIC ($\varepsilon_{PAR} = \varepsilon_{PERP} = 1.6$) AND ANISOTROPIC ($\varepsilon_{PAR} = 1.8$; $\varepsilon_{PERP} = 1.4$) COTTON-POLYESTER SUBSTRATE AT THE CENTRAL FREQUENCY OF EACH STRUCTURE (BENT RADIUS = 80 MM)

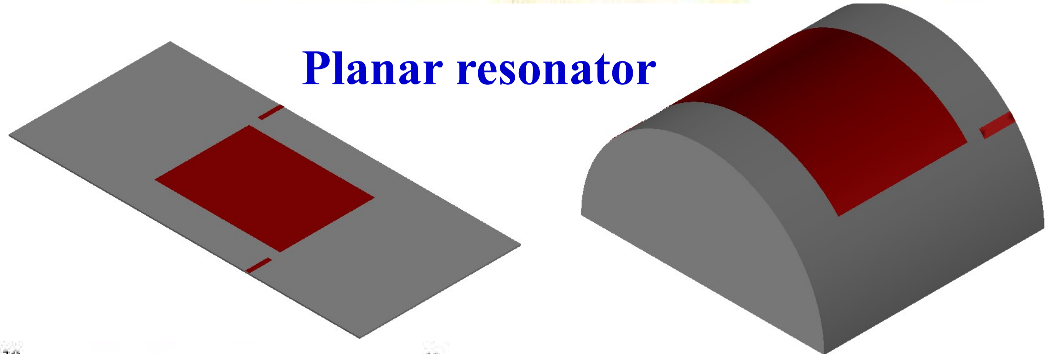
Patch ⇒ Parameter ⇓	Flat patch *(iso/aniso)*	Bent patch *(iso/aniso)*
Frequency, GHz	2.425/2.575	2.28/2.25
Directivity, dBi	6.7/7.4	5.7/5.1
Beam width, sterrad	1.87/1.71	2.21/2.30
Efficiency, %	55.3/58.0	58.6/57.2

P. I. Dankov, M. I. Tsatsova, and V. P. Levcheva (2017), "Investigation of Uniaxial Dielectric Anisotropy of Textile Fabrics and Its Influence over the Wearable Antennas' Behaviour", *PIERS'2017*, Singapore, Nov. 2017

Substrates with bi- or uni-axial anisotropy



Planar resonator



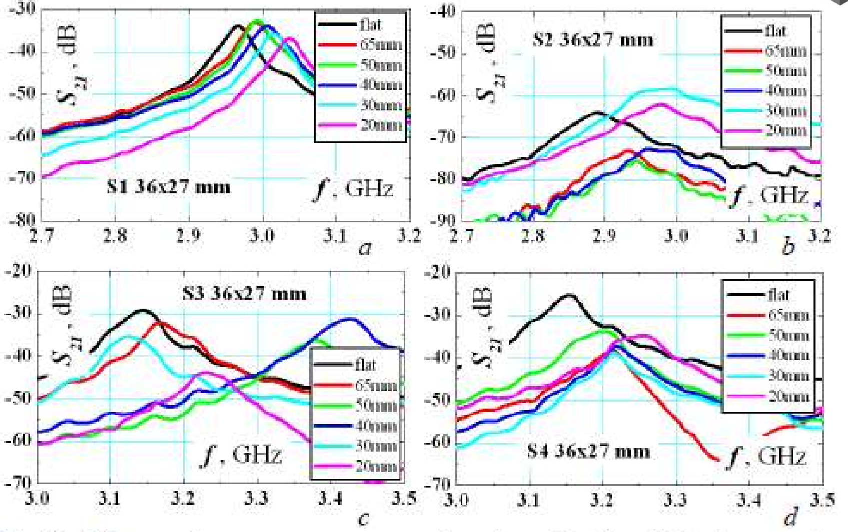


Fig. 9. Measured resonance curves of rectangular length-bent resonator 36x27 mm on substrates S1, S2, S3 and S4 (for lowest-order mode)

Isotropic substrate

Anisotropic substrate: ($\varepsilon_{par} > \varepsilon_{perp}$)

Evaluation of the dielectric anisotropy in textile fabrics

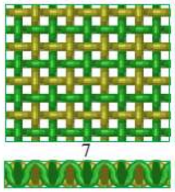
TABLE I. MEASURED DIELECTRIC PARAMETERS AND ANISOTROPY OF SOME CLASSICAL TEXTILE FABRICS (AVERAGED VALUES TAKEN FROM [11] FOR FREQUENCY INTERVAL 0-36 GHZ)

Textile fabric	t, mm	ε_{par}/$\tan\delta_{\varepsilon\_par}$	ε_{perp}/ $\tan\delta_{\varepsilon\_perp}$	Anisotropy $A_\varepsilon/A_{\tan\delta\varepsilon}$, %
Epoxy-based waterproof fabric	0.35	1.97/0.0095	1.83/0.0070	7.4/30
Waterproof fabric with breathability GORE-TEX® [16]	0.20	1.53/0.0057	1.38/0.0043	10.3/28
Weaved silk	0.19	1.60/0.028	1.54/0.0156	3.8/57
Weaved linen	0.65	1.65/0.043	1.58/0.044	4.3/-2.3
Weaved hemp fishnet	0.81	1.63/0.072	1.43/0.034	13.1/72
Natural leather	0.84	2.47/0.055	2.44/0.054	1.2/1.8
Weaved wool	2.10	1.28/0.026	1.21/0.015	5.6/54
Jersey knitted wool	5.50	1.40/0.024	1.26/0.021	10.5/13.3
Denim	0.93	1.69/0.027	1.61/0.030	4.8/-11
Cotton satin 5	0.25	1.58/0.019	1.45/0.013	8.6/38
Jersey knitted cotton	0.40	1.56/0.055	1.50/0.044	3.9/22.2

Table 2. Measured dielectric parameters of commercial GORE-TEX® fabrics in the X, K and Ka frequency bands

Sample	Frequency bands	ε_{par} /$\tan\delta_{\varepsilon\_par}$	ε_{perp} /$\tan\delta_{\varepsilon\_perp}$	Anisotropy $A_\varepsilon/A_{\tan\delta\varepsilon}$, %
1g. GORE-TEX® 3-layer fabric (0.2-mm thick)	X, Ku K Ka	1.55/0.0058 1.53/0.0056 1.50/0.0057	1.36/0.0045 1.38/0.0043 1.41/0.0040	13.1/25 10.3/26 6.9/35
2g. GORE-TEX® 4-layer fabric from original "Repair kit" with removed glue layers (0.22-mm thick)	X, Ku K Ka	1.51/0.0054 1.53/0.0053 1.53/0.0058	1.38/0.0039 1.39/0.0036 1.40/0.0033	9.0/32 9.6/38 8.9/55

1 – top view; 2, 3 – bottom view of the 1st and 2nd samples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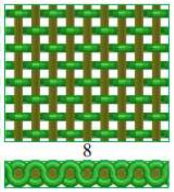
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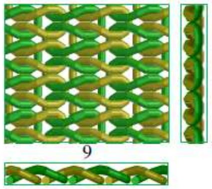
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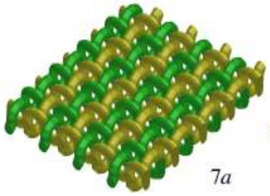
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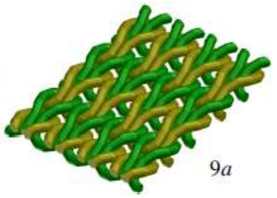
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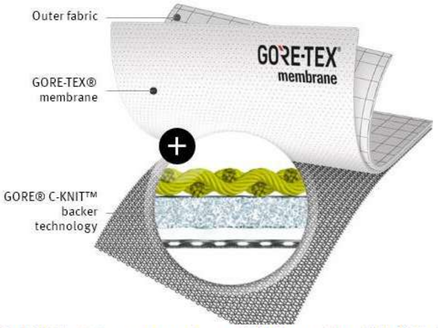
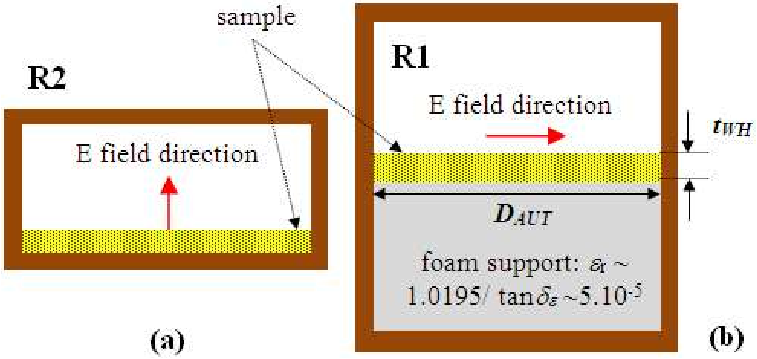


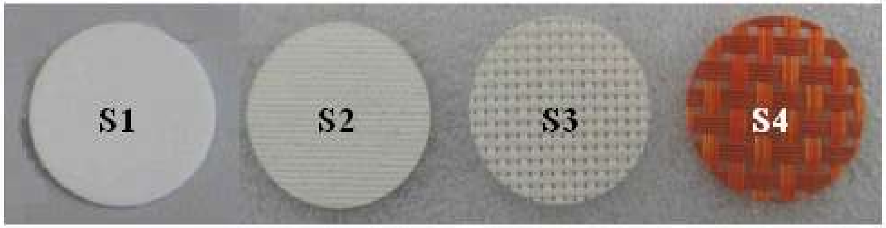
Table 3: Dielectric parameters of fish-net textile fabrics made by synthetic fibres with different density

Nets description	Surface image	Frequency bands	ε_{par}	ε_{perp}	Dielectric anisotropy A_ε, %
Rare fishnet		X, Ku K Ka	1.310 1.325 1.340	1.255 1.280 1.310	4.29 3.45 2.26
Medium to rare net		X, Ku K Ka	1.51 1.49 1.48	1.39 1.38 1.38	8.28 7.67 7.00
Medium density net		X, Ku K Ka	1.55 1.54 1.54	1.41 1.40 1.40	9.46 10.17 9.52
Medium to dense net		X, Ku K Ka	1.91 1.90 1.89	1.67 1.67 1.66	13.41 13.18 12.96
Dense net		X, Ku K Ka	2.16 2.21 2.37	1.81 1.90 1.94	17.63 15.09 19.95

Two-resonator method that support TE and TM modes with mutually perpendicular E fields



P. I. Dankov (2006), "Two-Resonator Method for Measurement of Dielectric Anisotropy in Multi-Layer Samples", *IEEE Trans. Microwave Theory Tech.*, MTT-54, April 2006, pp. 1534-1544



<u>Selected substrates for this research</u>: 1 isotropic and 3 anisotropic

TABLE II. MEASURED DIELECTRIC PARAMETERS AND ANISOTROPY OF SELECTED SAMPLES IN THIS RESEARCH (SEE FIG. 1)

Textile fabric	t, mm	ε_{par} / $\tan\delta_{\varepsilon\_par}$	ε_{perp} / $\tan\delta_{\varepsilon\_perp}$	Anisotropy $A_\varepsilon/A_{\tan\delta\varepsilon}$,%
S1 Teflon (PTFE)	0.40	2.048/0.0004	2.04/0.0004	0.40/0
S2 Textile 1 (fine woven linen, then impregnated)	0.40	2.065/0.021	1.95/0.020	5.7/4.9
S3 Textile 2 (coarse, woven)	0.80	2.030/0.0060	1.77/0.0046	13.7/26
S4 Textile 3 (very coarse, woven)	0.97	1.97/0.0064	1.76/0.0055	11.26/15

Investigation of bending effect in planar patches and resonators

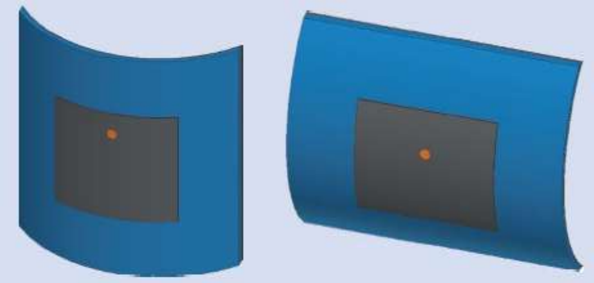


FIGURE 2. The antenna bending scenarios: (a) width bent (case A) and (b) length bent (case B).

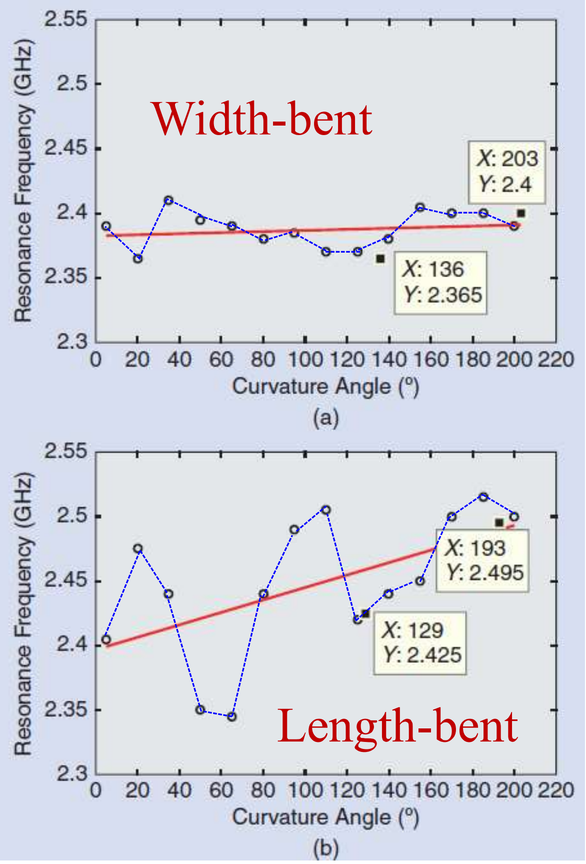
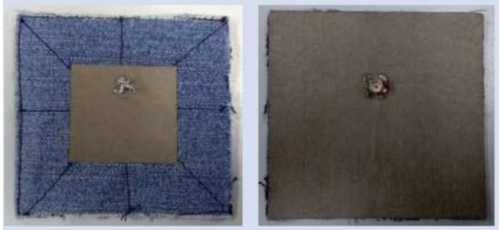
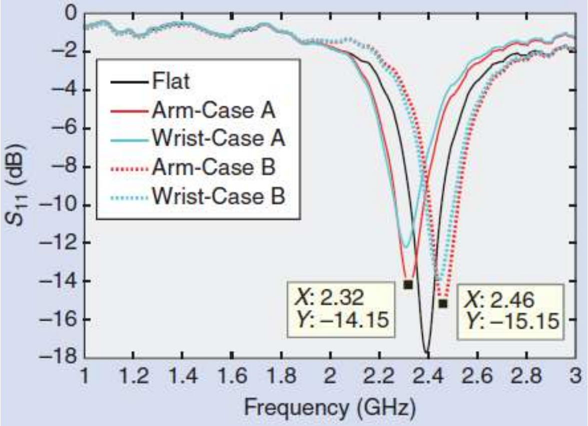


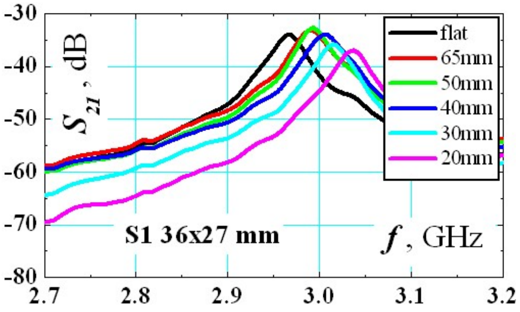
FIGURE 3. The simulated curvature angle impact on antenna resonant frequency for: (a) case A and (b) case B.

Source: D. Ferreira, P. Pires, R. Rodrigues, and R.F.S. Caldeirinha, “Wearable Textile Antennas (examining the effect of bending on their performance)”. Antennas & Propagation Magazine, June 2017, pp. 54-59, 10.1109/MAP.2017.2686093





⇐ How to explain ripples here?



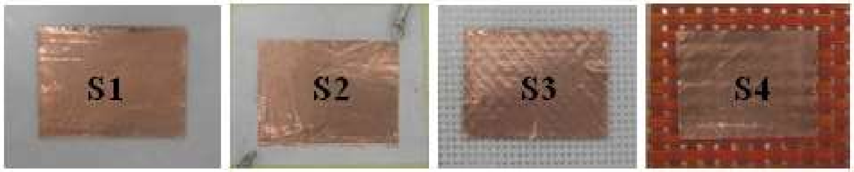


Fig. 4. Rectangular flat resonators 36 x 27 mm on samples S1, S2, S3, S4

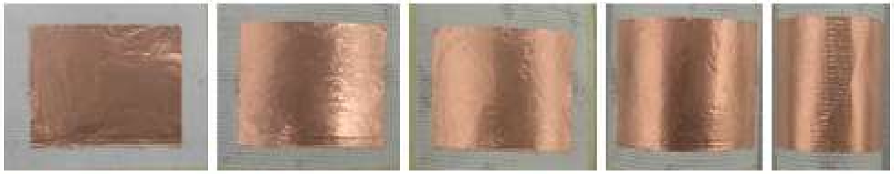


Fig. 5. Rectangular length-bent resonator 36x27 mm on sample S2 with bent diameters s ∞, 65, 50, 50, 30 and 20 mm

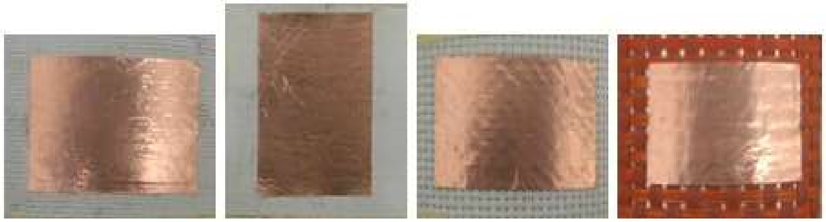
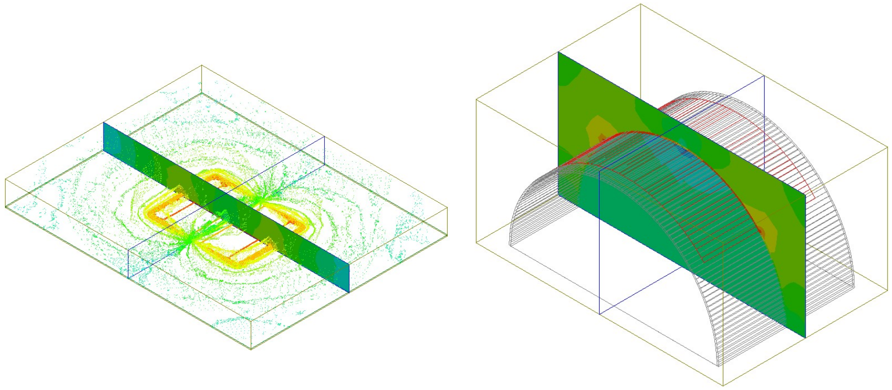
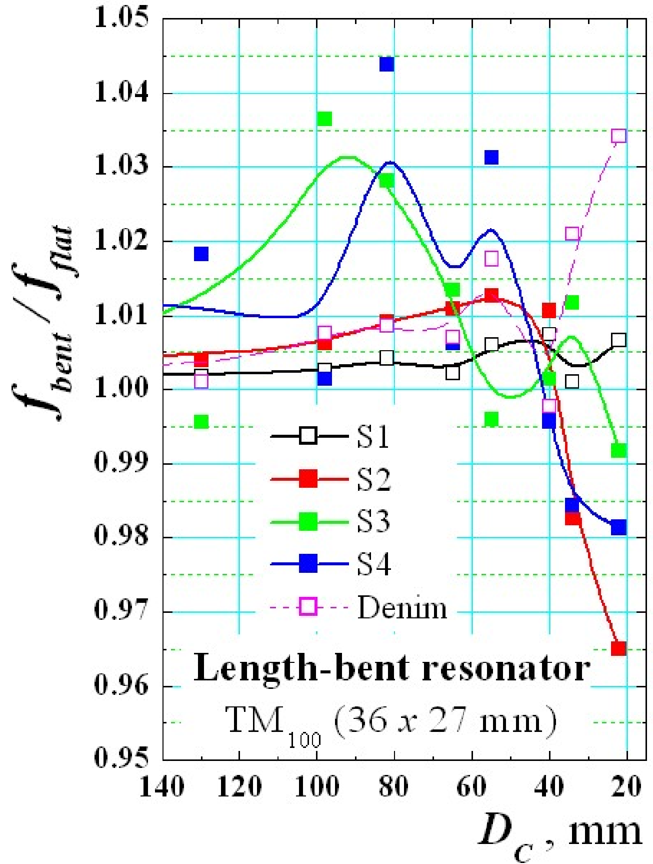


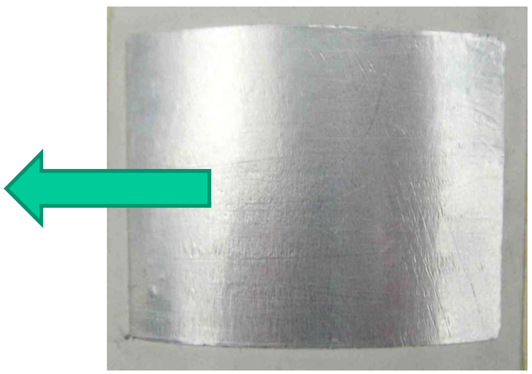
Fig. 6. Rectangular length- or width-bent resonator 36x27 mm on sample S2 with bent diameters s 65 mm; (also length-bent resonator on S3, S4)



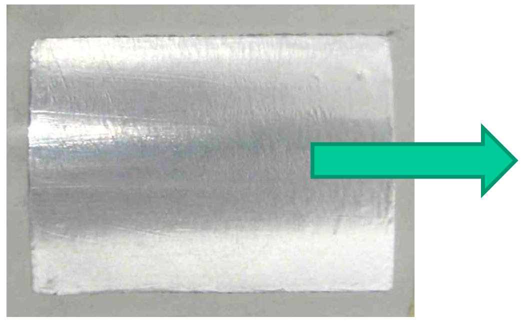
Simulated E-field distribution for TM_{100} mode

Comparison between the resonance frequencies of TM_{100} mode in length- and width-bent planar resonators on pure isotropic and anisotropic textile substrates

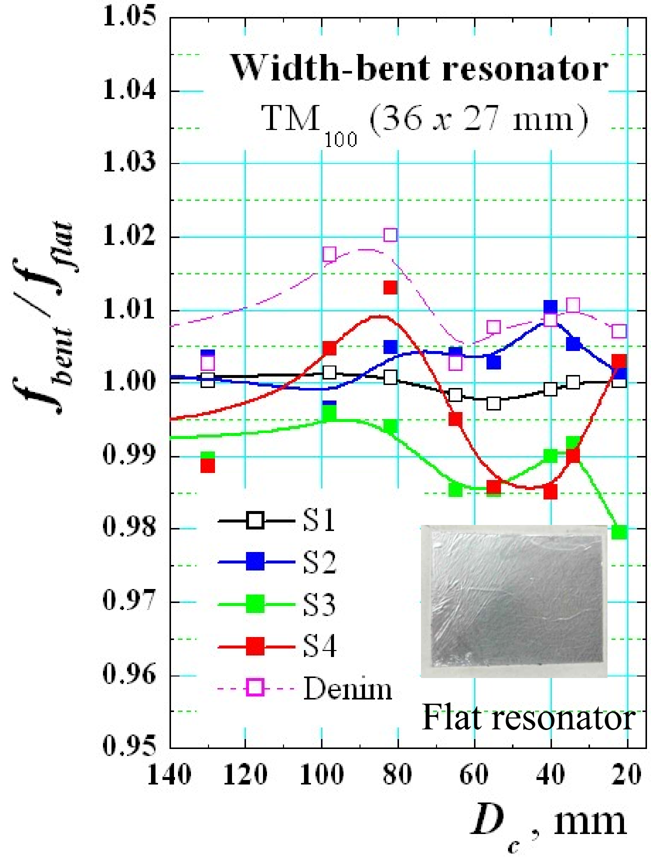




Length-bent resonators

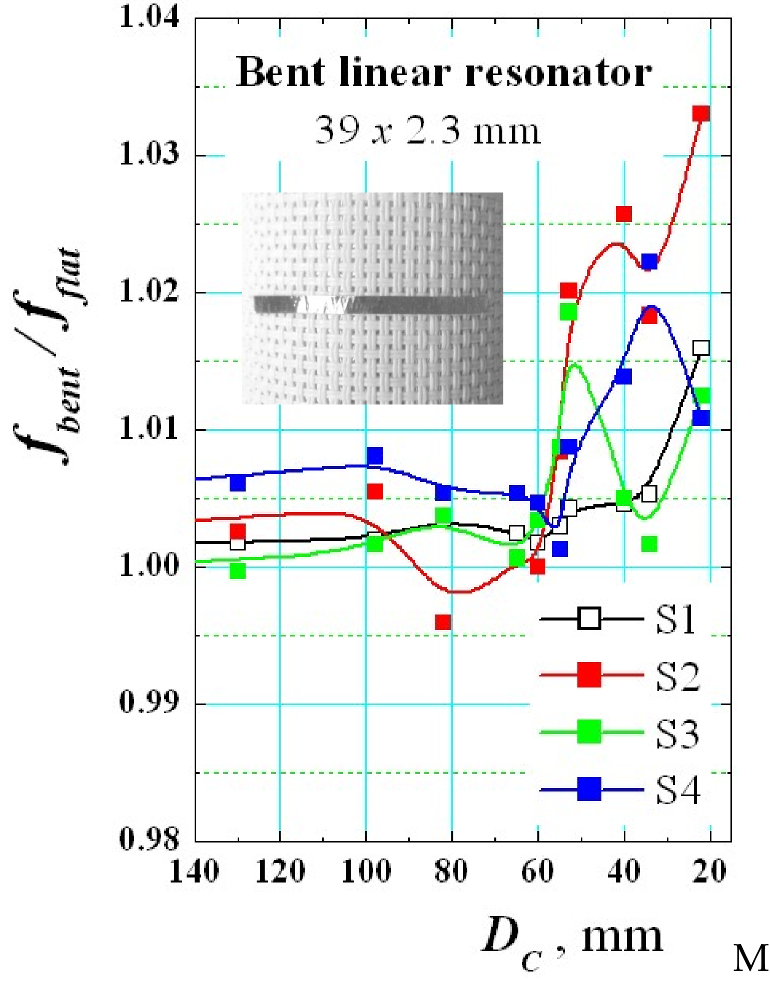


Width-bent resonator



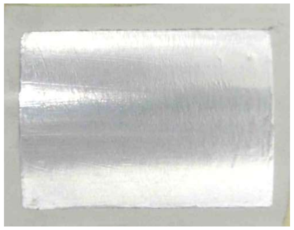
Observations: Only for isotropic substrates, we can observe a continuous increasing of the resonance frequency (with small ripples in the frame of measurement errors). Considerable bigger ripples have been observed in these dependences for anisotropic substrates (see also the previous slide). The simple explanation is: depending on the curvature diameter D_C, the local places with maximal E fields at the resonator edges have been changed and the effect of the local equivalent dielectric constant ε_{eq} ($\varepsilon_{par} > \varepsilon_{eq} > \varepsilon_{perp}$) in these maximums compensates or increases the effect of decreased resonator length due to the bending (more research has to be performed!).

Main benefit of this research: the effects of bending and anisotropy in resonators on isotropic and anisotropic substrates can be separated!



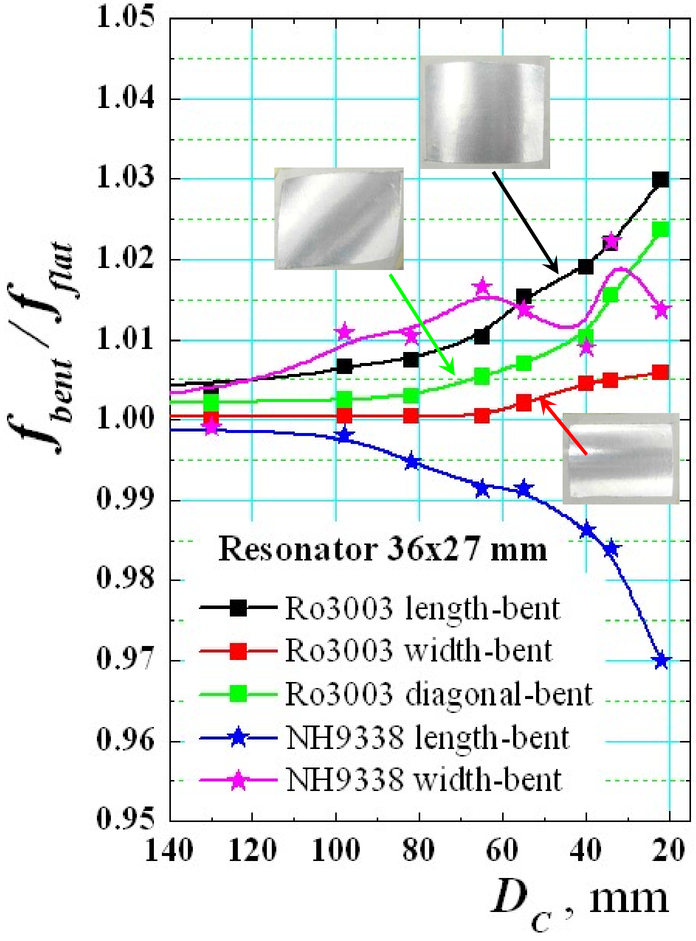
Measured normalized resonance frequencies of linear resonator on samples S1-S4: well observed differences in the resonance behaviour

Length-bent resonators



Width-bent resonators

Diagonal-bent resonators



Measured normalized resonance frequencies of length-; width- or diagonal-bent rectangular resonator 36x27 mm on commercial substrates: isotropic Ro3003 and anisotropic NH9338 (for mode TM_{100}). Note: the resonance frequency only increases for bent resonators on isotropic substrate due to an effective decreasing of the resonator length (biggest for length-bent; smallest for width-bent; medium for diagonal-bent resonator – well explainable effects)

References and future work

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Future work:

These preliminary obtained results show that we have to continue the investigations – to spread the research to more combinations of anisotropy parameters and sizes of used resonators with different curvatures; to spread research from resonators to antenna patches, to additionally investigate the influences of the considered effects on the radiation patterns and single patch antenna gain and to prove the measured effect with full-wave simulations. The obtained set of results could be helpful for the development of the wearable antennas based on metamaterials (with expressed anisotropy) with flat and bent architecture.

Plamen I. Dankov is an Assoc. Professor in Faculty of Physics, Sofia University, Bulgaria and material characterization consultant of several companies. His education activities are in the area of microwave and wireless technique, measurements, antennas, aerospace engineering. He is chair of two Master programs. His research interests include microwave gyrotropic devices, microwave material characterization, antennas, EMC problems, microwave measurements, 3D electro-magnetic simulations, small satellites. He has more than 150 scientific and popular publications in these areas. Dr. P. Dankov is IEEE Member in 4 Societies: MTT, A&P, I&M, Aerospace. He was member of GA of EuMA and Group 8 representative (2013-2016). He is POC of UNISEC Global in Japan and Secretary of UNISEC Bulgaria.

Valda P. Levcheva is a Research engineer in Faculty of Physics, Sofia University, Bulgaria. She is preparing her PhD thesis in the area of material characterization of microwave substrates, absorbers, textile antennas, crystalline materials. She is involved in the teaching in two Master programs in areas of microwave electronics, antennas, microwave measurement and wireless communications.

Praveen Kumar Sharma is an Assistant Professor in Birla Institute of Technology and Science (BITS), ECE Department, Pilani, Rajasthan, India. He is preparing his PhD thesis in the area of wearable antennas on flexible PDMS substrate, UWB antennas and arrays with metamaterials and bending effects of wearable antennas with metamaterials.

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